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Professor Jenkins

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Southern California
Dept of Electrical Engineering Systems
Signal and Image Processing Institute
3740 McClintock Avenue Suite 404
Los Angeles, CA 90089-2564

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13. ABSTRACT *(Maximum 200 words)*

Technical accomplishments under the grant, "Photonic Technology Development for Densely Interconnected Neural Networks: Augmentation Award" (AFOSR Grant No. F49620-93-1-0445), B. K. Jenkins, P.I., are described. They include an analysis of convergence conditions and properties of backward-error-propagation learning in photorefractive-based optical neural networks. The analysis includes implementations based on fully coherent single-source architectures and on incoherent/coherent multiple-source architectures. Also analyzed in terms of their effect on optical neural network learning are spatial light modulator limitations such as finite modulator contrast ratio, detector noise, and limited detector dynamic range. Additionally, we have developed a technique for compensating for photorefractive grating decay during neural-network learning, by varying two parameters, spatial-light-modulator gain and photorefractive-crystal exposure energy, according to a prescribed schedule.

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Photonic Technology Development for Densely Interconnected Neural Networks: Augmentation Award

AFOSR Grant No. F49620-93-1-0445

Final Technical Report
Reporting Period: 1 September 1993 - 31 August 1996

B. Keith Jenkins, P.I.

Department of Electrical Engineering-Systems
Signal and Image Processing Institute, and Center for Neural Engineering
University of Southern California
Los Angeles, California 90089-2564

Submitted 24 January 1997

1. Summary of Technical Progress Made Under this Grant By Each Supported Student

1.1 Convergence of Backward Error Propagation Learning in Photorefractive Crystals (primary student on this effort: Gregory C. Petrisor)

We have analytically determined that the backward-error-propagation learning algorithm has a well defined region of convergence (in neural learning-parameter space) for two classes of photorefractive-based optical neural network architectures, and derive a set of sufficient conditions for the optical neural network to converge. The analysis includes characteristics of photorefractive materials such as grating decay under illumination and linearity of response as used in an optical architecture versus ideal neural-network-model weight updates. The theoretically proven results are also verified by means of simulation. The convergence conditions are related to two experimental parameters, system gain and photorefractive-crystal exposure energy [1].

We have also investigated the effects of limitations of spatial light modulators on the performance of the same classes of optical neural-network architectures. Phenomena studied include non-ideal modulator contrast ratio, limited detector dynamic range, and detection noise [2].

1.2 Gain and Exposure Scheduling to Compensate for Photorefractive Neural-Network Weight Decay (primary student on this effort: Adam A. Goldstein)

We have developed a gain and exposure schedule that theoretically eliminates the effect of photorefractive weight decay for the general class of outer-product neural-network learning algorithms (*e.g.*, back propagation, Widrow-Hoff, perceptron). This schedule compensates for photorefractive diffraction efficiency decay by iteratively increasing the spatial-light-modulator transfer function gain and decreasing the weight-update exposure time. Simulation results for the scheduling procedure, as applied to back-propagation learning for the exclusive-or problem, show improved learning performance compared with results for networks trained without scheduling [3].

2. Publications

[1] G. C. Petrisor, A. A. Goldstein, B. K. Jenkins, E. J. Herbulock, and A. R. Tanguay, Jr., "Convergence of backward-error-propagation learning in photorefractive crystals," *Applied Optics*, Vol. 35, No. 8, pp. 1328-1343 (10 March 1996).

[2] G. C. Petrisor, *Convergence of Backward-Error-Propagation Learning in Photorefractive Crystals*, Ph.D. thesis, USC-SIPI Report No. 303 (Signal and Image Processing Institute, University of Southern California, Los Angeles, California, 1996).

[3] A. A. Goldstein, G. C. Petrisor, and B. K. Jenkins, "Gain and exposure scheduling to compensate for photorefractive neural-network weight decay," *Optics Letters*, Vol. 20, No. 6, pp. 611-613 (15 March 1995).

3. Summary of Academic Progress Made During the Period of this Grant By Each Supported Student

3.1 Gregory C. Petrisor

Mr. Petrisor's grades have been well above the grades needed for receiving the Ph.D. degree. He has completed his course work and his Ph.D. research, and passed his final oral thesis defense near the end of this grant period. His official Ph.D. graduation date was in December 1996.

3.2 Adam A. Goldstein

Supported in part by this grant and in part by other grants, Mr. Goldstein's grades have also been well above the grades needed for receiving the Ph.D. degree. He has also completed his course work and his Ph.D. research, and passed his final oral thesis defense in January 1997, a few months after the end of this grant.